A DIFFUSE RADAR SCATTERING MODEL FROM MARTIAN SURFACE ROCKS

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Remote sensing of Mars has been done with a variety of instrumentation at a variety of wavelengths. Jakosky and Christensen (1986) have shown that many of these data sets can be reconciled with a surface model of bonded fines (or duricrust) which varies widely across the surface and a surface rock distribution which varies less so. Recently, a surface rock distribution map from -60 to +60° latitude has been generated by Christensen (1986). Our objective is to model the diffuse component of radar reflection based on this surface distribution of rocks. The diffuse, rather than specular, scattering is modeled here because the diffuse component arises due to scattering from rocks with sizes on the order of the wavelength of the radar beam. Scattering for radio waves of 12.5 cm wavelength is then indicative of the meter-scale and smaller structure of the surface. The specular term is indicative of large-scale surface undulations and should not be causally related to other surface physical properties. A model of the diffuse component could help us compare various radar and infrared data sets and further constrain the nature of the martian surface.

Based on the images of the Viking Lander sites and radar measurements, diffuse scatterers do not appear to dominate the Martian surface. The scattering particles are irregularly shaped and sized and may reside on top of or within a dielectric discontinuity; this precludes a ready analytical solution to the scattering problem. Therefore, a simplified model of diffuse scattering is undertaken.

Although it has been shown that multiple scattering by subsurface rocks may make a significant contribution to the returned diffuse component in radar scattering (Pollack and Whitehill, 1972), our simplified model assumes that only the rocks on the surface will contribute. It is assumed that the rocks are non-absorbing, so that all power extracted from the beam is scattered (i.e., a single scattering albedo of one). Also, it is assumed that the power is scattered isotropically, and the scattering efficiency, Q, is taken to be one. This latter assumption is consistent with the Mie-scattering calculations of Hansen and Travis (1974) for particles of size parameter 1 to 6. The returned power is normalized to that returned from a smooth planet, so that common factors (e.g., incident power) divide out. The total power returned is then proportional to the projected fractional rock coverage integrated over the visible disk. Integration in one dimension, along lines of constant doppler shift, can be performed to obtain the cross section as a function of doppler shift, in a similar format to actual radar measurements.

There are two principle ways to express the rock distribution of a spherical surface projected onto a disk. Further from the center of the disk the surface rock distribution is viewed at an increasingly oblique angle. If the rocks are sitting on the surface, the projected fractional surface coverage is much higher at the limbs than it is normal to the surface, at disk center. We take the apparent surface distribution to be given by $f=1-\exp(-\tau/\cos i)$, where τ is a parameter used to fit the value of the rock abundance when viewed normal to the surface and i is the angle between the surface normal and the

return beam. The angle i varies from 0 to 90° over the face of the planetary disk, so rock abundances vary from a nominal value (e.g., 10%) at the subradar point (disk center) to 100% at the limbs of the planet. This is called, henceforth, the 'exponential model'. Alternatively, the surface distribution can be modeled as flat rocks imbedded in the surface, the 'cobblestone' model. Here, the surface fraction covered by rocks does not depend on incidence angle, and a planet of uniform coverage is represented by that uniform value (e.g., 10%) everywhere.

Both the cobblestone and exponential models were applied to a planet of uniform fractional rock coverage with values ranging from 5 to 20%. This yielded cross section versus Doppler shift curves which were reasonable in shape, and total cross sections for the planet between 0.010 and 0.080, depending on the rock abundance and model type. These values appeared reasonable in light of the measured diffuse cross sections between 0.049 and 0.092 (Harmon and Ostro, 1985). Finally, we applied the exponential and cobblestone models to the map of rock coverage (Christensen, 1986), and compared the results to the published diffuse radar scattering curves (Harmon and Ostro,1985; Harmon, et al., 1982, hereafter, HO and HCO, respectively).

We found that although neither model fit the measured data, the models gave values that were reasonable. The broad shape of the cobblestone model was in reasonable agreement with the data. The magnitudes of the cross section curves as well as the total cross section as a function of longitude were lower than the values given by HO and HCO by a factor of 2 or 3; but given the general assumptions of the model we did not expect to do better. The total cross section as a function of longitude is also well correlated with the 2.5-cm radio emission curve, which is to be expected because both the surface rock map and the radio emission are correlated to thermal inertia (Jakosky and Christensen, 1986).

The following aspects were in poor agreement with the data. The shape of the exponential model was in serious disagreement with the data due to a large degree of limb enhancement. Also, both models have a convex shape for large doppler shifts whereas HO and HCO results are concave in this region. This disagreement could be due to the effects of diffraction or multiple scattering at highly oblique angles of incidence. Another disagreement was the lack of duplication of small-scale features identified by HO and HCO. The locations of these features, as determined by HCO, did not correspond to any obvious features in the surface rock map. Also, there was no run-to-run correspondence between the magnitudes of the modeled and actual cross section curves. This may indicate the sensitivity of the actual measurements to scattering elements in the subsurface or in the polar region, for which we have no data. Another problem is the lack of uniqueness in the surface map. Twice as many scattering elements of one-half the size would produce the same thermal contrasts, but would have very different radar scattering properties. This implies the surface map derived from thermal contrasts is dependent on the assumed size of the scattering elements.

In an effort to bring the model into better agreement with the actual measurements we are currently examining two possibilities. We plan to vary the surface distribution of rocks in the polar regions to see if some of the features reported by HCO could be accounted for. Also, we plan to vary the surface distribution in the latitude and longitude bands which correspond to

the HCO features to see if a distribution which is consistent with the observed radar scattering as well as the thermal contrasts can be obtained.

REFERENCES

Christensen, P.R., The Spatial Distribution of Rocks on Mars, Icarus, in press, 1986.

Hansen, J.E. and L.D. Travis, Light Scattering in Planetary Atmospheres, Space Sci. Rev. 16, 527-610, 1974.

Harmon, J.K., D.B. Campbell, and S.J. Ostro, Dual-Polarization Radar Observations of Mars: Tharsis and Environs, Icarus 52, 171-187, 1982.

Harmon, J.K. and S.J. Ostro, Mars: Dual-Polarization Radar Observations with Extended Coverage, Icarus 62, 110-128, 1985.

Jakosky, B.M. and P.R. Christensen, Global Duricrust on Mars: Analysis of Remote-Sensing Data, J. Geophys. Res. 91, 3547-3559, 1986.

Pollack, J.B. and L. Whitehill, A Multiple Scattering Model of the Diffuse Component of Lunar Radar Echoes, J. Geophys. Res. 77, 4289-4303, 1972.